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no. 307

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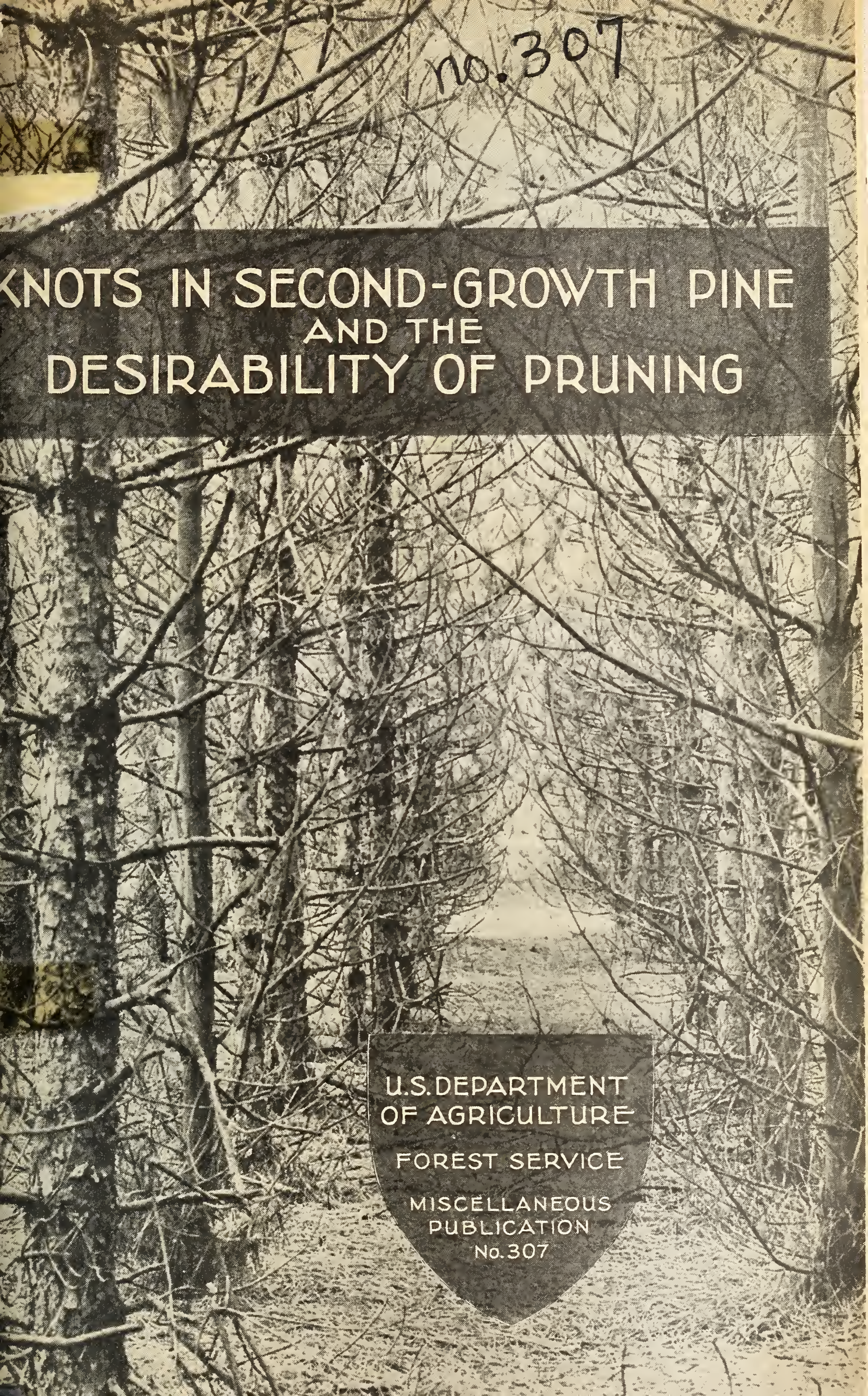
# AND THE
# DESIRABILITY OF PRUNING



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# KNOTS IN SECOND-GROWTH PINE AND THE DESIRABILITY OF PRUNING

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## INTRODUCTION

More than one-fourth of the entire land area of the United States is still forest or suited by nature to the growth of timber. In farm woodlands and other small holdings are 185 million acres, the proper use of which is of profound importance to the Nation's prosperity in that they afford a source of wealth and employment to thousands of farmers. A large portion of this land is now producing only knotty second-growth timber. It is therefore imperative that farm wood-lot and other timber owners know the effect of knots on the quality of lumber being proudced on their lands and the methods to employ in order to obtain the maximum amount of clear wood.

Clear lumber as produced in American sawmills is now cut principally from virgin-growth timber 200 to 500 years of age and upwards. The clear wood was formed only in the outer layers of the lower part of the tree trunks. Many of the trees were of sawlog size before they produced any clear lumber—for nature's method of producing clear wood is exceedingly slow.

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[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

In the more closely stocked stands, the death of the side branches from lack of sunlight is the first step in this snail's-pace process. Then, through a period of disintegration and decay frequently exceeding the lifetime of a man, the dead branches gradually weaken and break off, leaving irregular stubs of varying lengths that often protrude from the trunk for many years before they are grown over. Later when the trees are cut for lumber these persistent branch stubs appear as knots and cause serious degrade.

Many of our second-growth stands are understocked, and as a result natural pruning of the trees will not take place for a great many years. With a constantly increasing proportion of second growth in our forests, the problem of improving the quality of timber and at the same time decreasing the rotation period is being given serious consideration by the Forest Service in different parts of the country.

As a part of a research program dealing with the influence of growth conditions upon wood quality, the Forest Products Laboratory has made the following study of the development of knots in timber trees. Although knots are an inherent part of every timber tree and are familiar to all users of lumber, nevertheless many people do not have a clear conception of what a knot is or how it develops in different species and under different forest conditions. The present study provides information in regard to the formation of knots, natural pruning of forest trees, and the advantages that may be derived by the removal of the lower branches while the trees are small. The information should be of value to wood-lot owners, timber growers, and foresters in pointing out the desirability of artificial pruning as a silvicultural means of improving the quality of lumber from second-growth stands.

The present study constitutes only one phase of the general problem of pruning to reduce the knottiness of the lumber cut from forest trees grown on short rotation. In order to obtain efficient management and utilization of our second-growth pine timber, which now constitutes a large and increasingly important portion of our forest land, farm wood-lot and other timberland owners are still in need of more definite information on pruning costs and methods, and on many other pruning problems, such as the time of year pruning should be done, the relation between the size of branch to be pruned and the rapidity of healing, and the extent pruning should be carried out in a given stand of timber. Attempts to answer the foregoing questions and to improve pruning methods by mechanical means are currently under way at the Forest Products Laboratory.

## SPECIES AND METHOD OF STUDY

The species dealt with in this publication are northern white (*Pinus strobus*), red (*P. resinosa*), loblolly (*P. taeda*), shortleaf (*P. echinata*), slash (*P. caribaea*), and longleaf (*P. palustris*) pines. Knots from unpruned branches were studied in all six species; knots remaining after pruning were studied in northern white and red pines.

The method of study consisted of sawing open the stems of second-growth trees in such a way that a longitudinal section of every knot was revealed (fig. 1). The trunks of trees were first cut into billets 8 to 10 inches in length, care being taken to make all crosscuts in the clear wood between the branches. Next, these billets were sawed

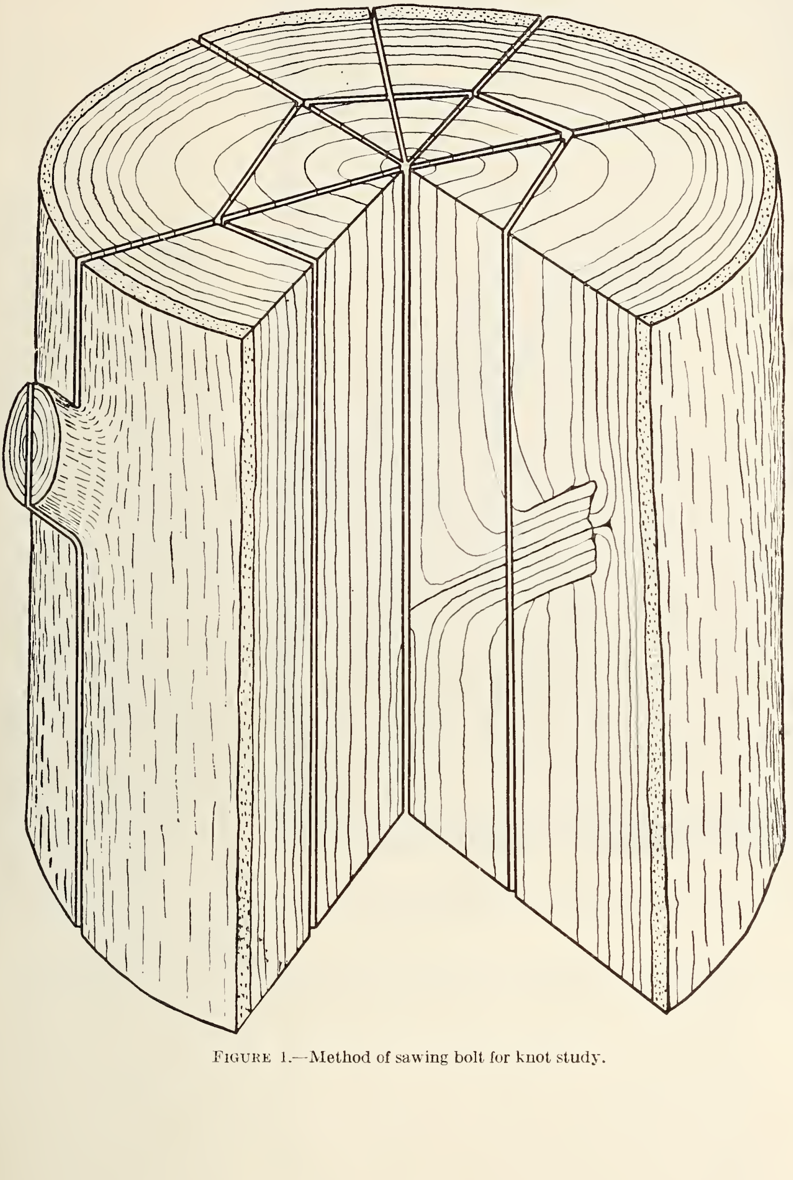

FIGURE 1.—Method of sawing bolt for knot study.

radially on a band saw, the cuts being made to bisect all knots and knot scars visible on the outside of the stem; other cuts made near the center at right angles to the radius exposed the presence of any knots that had been completely overgrown. These knots likewise were bisected longitudinally. The material was then ready for making measurements (fig. 2).

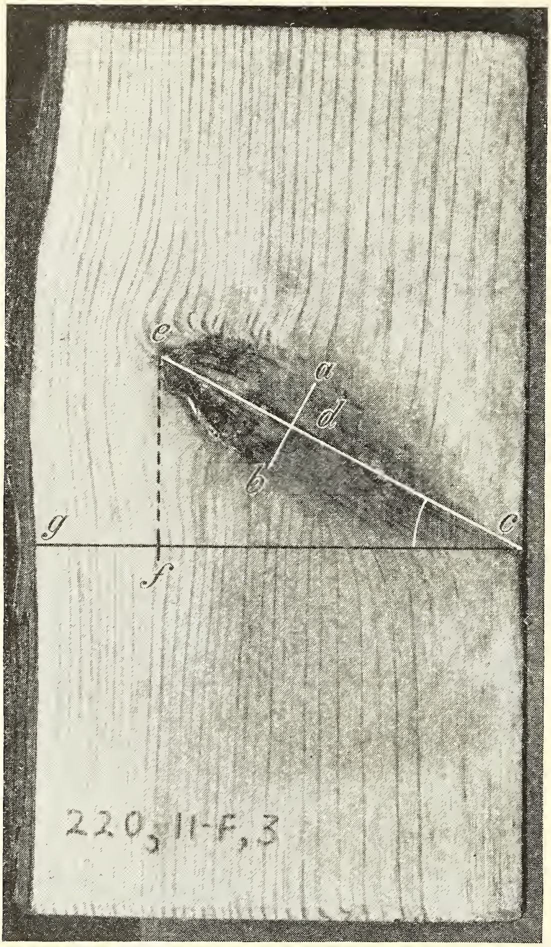

FIGURE 2.—Measurements recorded in knot study: *a–b*, Diameter of knot; *c–d*, length of live portion; *d–e*, length of dead portion; *e, c, f*, degree of slope above horizontal; *c–f*, horizontal projection of knot; *f–g*, clear wood outside of knot.

The information recorded included the height above the stump of successive whorls of branches, the number and the size of knots at each branching, the size and age at which the limbs forming the knots died, the length of time the dead limbs or stubs persisted on the tree trunk, the length of the overgrown dead portion of the limbs, and the presence of bark or pitch in or around the knots. This information was secured from stands up to 86 years of age without the necessity of making observations and keeping records over a long period. In other words, the tree's own record over the years was copied and interpreted.

The number of knots examined in the six species and other pertinent information concerning the trees and stands are given in table 1.

TABLE 1.—*Description of stands and trees investigated in knot study*

| Species and locality | Stand No. | Trees per acre | Trees studied | | | | | | | Composition of stand |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Number | Range in age | Range in diameter at breast height | Range in total height | Average annual growth in height in first 20 feet | Knots per tree in first 20 feet | Range of clear length [1] | |
| | | *Number* | | *Years* | *Inches* | *Feet* | *Inches* | *Number* | *Feet* | |
| Northern white pine, Wisconsin | 1 | 450 | 5 | 52–56 | 8–12 | 67–69 | 18 | 77 | 0 – 5 | Northern white and red pines, large-toothed aspen, paper birch, and other miscellaneous hardwoods. |
| | 2 | 1,080 | 5 | 56–58 | 8–11 | 60–67 | 12 | 91 | 0 | Nearly pure northern white and red pines. |
| | 3 | 450 | 7 | 52–56 | 8–13 | 57–69 | 14 | 81 | 0 – 4 | Almost pure northern white pine, some red pine, and scattered white birch and small trees of other northern hardwood species. |
| | 4 | 400 | 5 | 85–89 | 9–12 | 59–70 | 10 | 88 | 1 – 8 | Mixed northern white pine and red pine overstory, with understory of balsam fir and young hardwoods. |
| Red pine, Wisconsin | 5 | 450 | 5 | 54–65 | 10–12 | 64–67 | 13 | 67 | 1.5– 4 | Same as stand No. 1. |
| | 6 | 1,080 | 5 | 54–58 | 8–11 | 62–67 | 14 | 76 | 1.5– 9 | Same as stand No. 2. |
| | 7 | 450 | 3 | 52–54 | 11–14 | 66–68 | 16 | 80 | 2 – 8.5 | Same as stand No. 3. |
| | 8 | 400 | 5 | 81–86 | 9–10 | 67–72 | 13 | 78 | 8.5–22 | Same as stand No. 4. |
| Loblolly pine, North Carolina | 9 | 485 | 5 | 40–45 | 8–10 | 60–78 | 30 | 87 | 2 –22 | Pure stand of old-field loblolly pine. |
| | 10 | 370 | 4 | 45–72 | 8–12 | 64–77 | 18 | 64 | 13 –24 | Loblolly pine trees and mixed hardwoods, principally oaks and hickories. |
| Loblolly pine, Mississippi | 11 | 400 | 5 | 21–25 | 7–10 | 52–57 | 20 | 68 | 4 –16 | Nearly pure stand of second-growth loblolly pine—a few scattered hardwoods remaining from original forest. |
| | 12 | 300 | 5 | 26–30 | 10–14 | 62–70 | 30 | 53 | 8 –24 | Second-growth loblolly adjoining hardwoods along watercourse, some hardwoods in mixture. |
| Shortleaf pine, North Carolina | 13 | 550 | 5 | 44–45 | 9–10 | 60–65 | 22 | 114 | 0 –16.5 | Pure stand of old-field shortleaf pine. |
| | 14 | 600 | 5 | 40–51 | 8–11 | 45–61 | 14 | 98 | 12.5–18 | Shortleaf pine and mixed hardwoods, principally oaks. |
| Slash pine, Florida | 15 | 330 | 5 | 18–22 | 9–11 | 59–63 | 24 | 53 | 2 – 9 | Pure stand of second-growth slash pine. |
| Slash pine, Mississippi | 16 | 350 | 7 | 25–40 | 6– 9 | 45–70 | 27 | 51 | 7 –21 | Do. |
| | 17 | 460 | 4 | 23–49 | 8–10 | 49–60 | 24 | 48 | 4.5–22 | Slash pine trees mixed with young hardwoods along water course. |
| Longleaf pine, Florida | 18 | 480 | 5 | 25–30 | 9–11 | 62–72 | 34 | 32 | 2.5– 5.5 | Pure stand of second-growth longleaf pine. |
| Longleaf pine, Mississippi | 19 | 350 | 5 | 25–30 | 7–11 | 47–50 | 27 | 45 | 2.5– 9.5 | Do. |
| | 20 | 530 | 5 | 20–30 | 5– 7 | 46–56 | 34 | 33 | 2 – 7 | Do. |

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[1] Clear length is based upon the section of the trunk in which the knots are covered over by 1 or more annual rings of woody growth—not on the superficial appearance outside of the bark.

### DEFINITION OF A KNOT

A knot is that portion of a branch, or limb, that has become incorporated in the body of a tree. An intergrown knot is one in which the rings of annual growth are completely intergrown with those of the surrounding wood (fig. 3, *A*). If the rings of annual growth are not intergrown with those of the surrounding wood the knot is known as an encased knot (fig. 3, *B*). If the sawed section of a knot is oval or circular it is known as a round knot. A branch or limb which in the process of lumber manufacture has been sawed in a lengthwise direction is known as a spike knot (fig. 4).

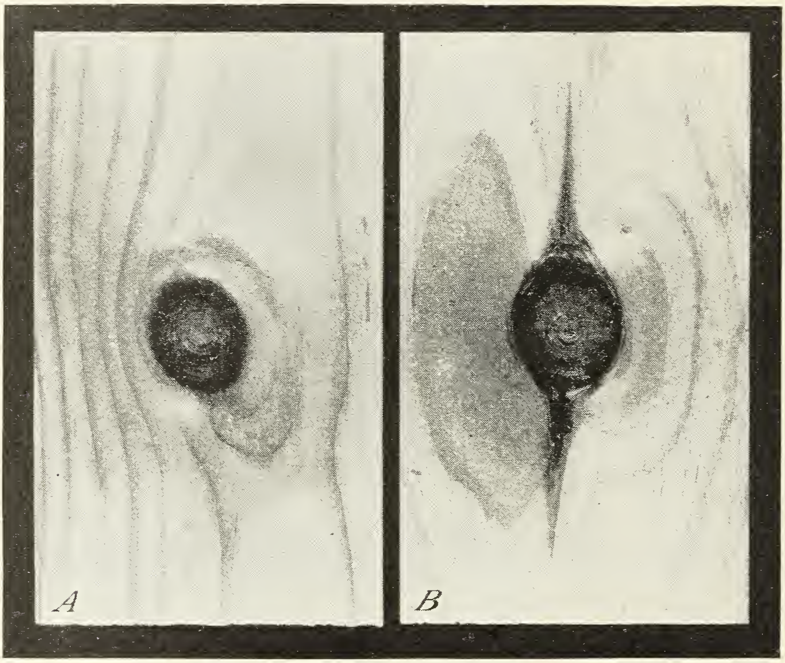

FIGURE 3.—*A*, Intergrown or "live" knot formed from portion of a living branch; *B*, encased or "dead" knot formed by the inclusion of a portion of a dead branch.

Enlargements of the tree trunk which give rise to irregularities of the growth layers surrounding a knot are sometimes erroneously considered as a part of the knot. Such enlargements are technically termed nodal swellings. The knot consists only of the occluded portion of the branch.

As long as a branch remains alive it is an integral part of the tree and its growth layers are an uninterrupted extension from those of the trunk of the tree. The growth layers, however, change direction usually rather abruptly at the junction of the branch with the trunk.

### MODE OF BRANCHING IN CONIFERS

The mode of branching in conifers as in all timber trees influence sthe number and location of knots in a tree. As a rule, the first knots are initiated at the base of the terminal bud at the beginning of the second year of growth of a seedling when the lateral buds there develop into branches (fig. 5). The next year a new set of branches is started as

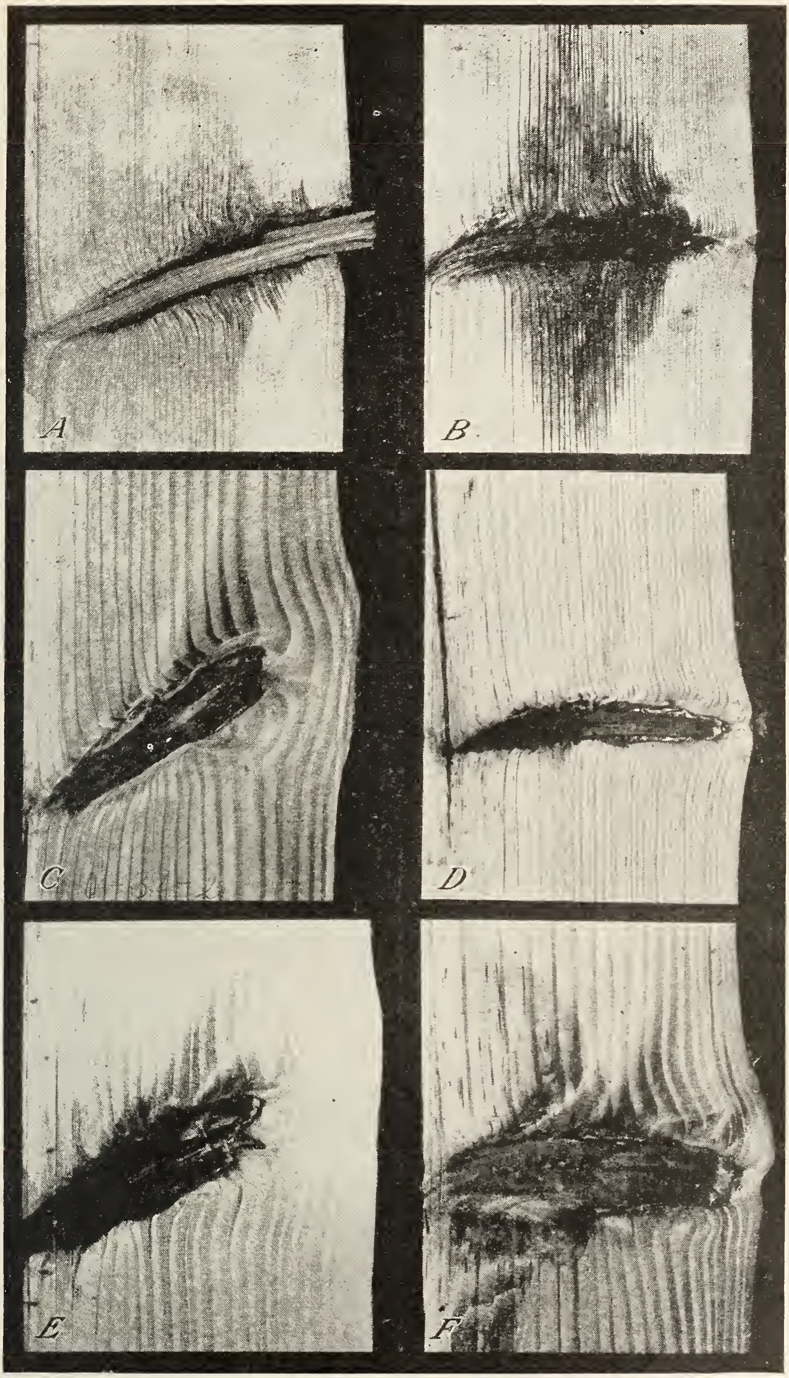

FIGURE 4.—Typical spike knots in six species of conifers: *A*, Northern white pine; *B*, red pine; *C*, loblolly pine; *D*, shortleaf pine; *E*, slash pine; *F*, longleaf pine.

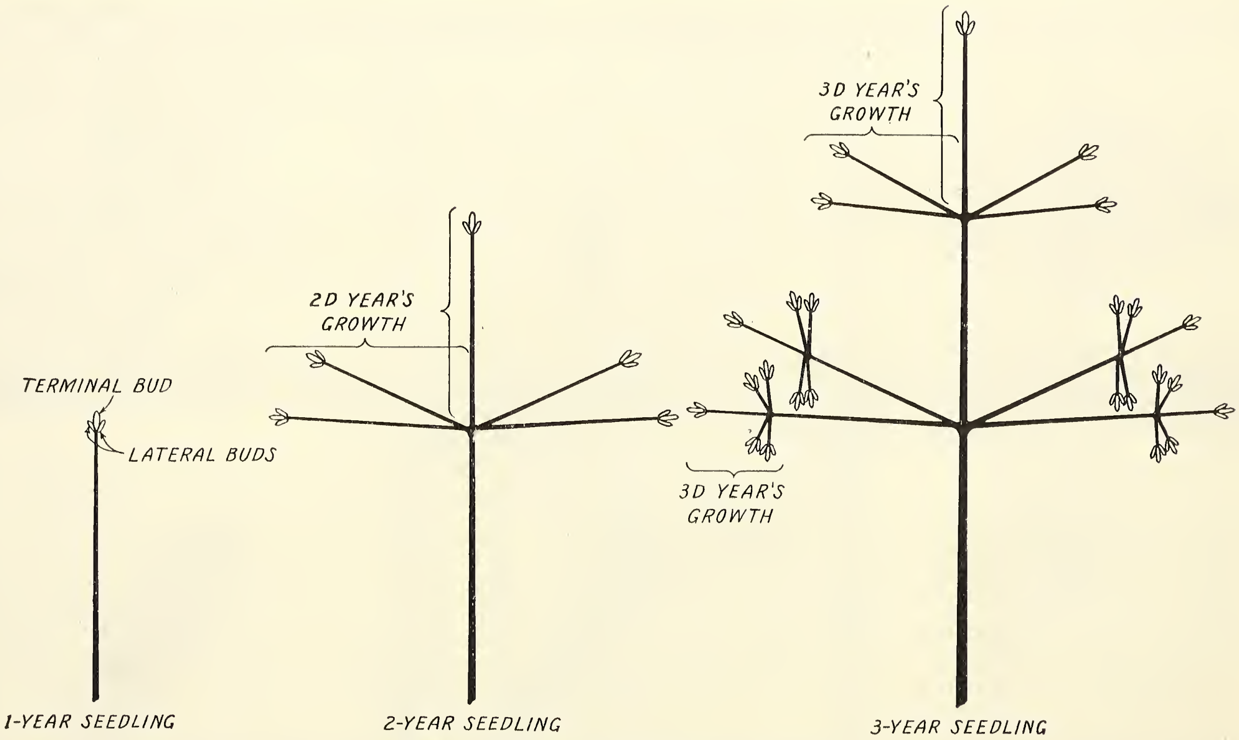

FIGURE 5.—Development of side branches in pine seedlings.

the secondary buds of the leading shoot again lengthen. Each of the lateral shoots of the previous year follows the example of the central leader and produces its own system of branches. The point on a stem at which branches arise is known as a node. In some species, like northern white pine, nodes usually form only at the termination of each year's growth. In other species, notably the southern pines, lateral branches may develop from buds which arise along the leading axial shoot between the annual nodes.

### TOLERANCE

The degree of shading under which the foliage of a tree is able to endure and remain alive is spoken of as tolerance. In species of low tolerance the lower branches of the trees or secondary branches within the crowns die more quickly when sunlight is denied them than do the branches of the more tolerant species. Under equal forest conditions, branches on tolerant species remain green longer and produce larger intergrown, or "live," knots than do branches on intolerant species. There does not appear to be any relationship, however, between tolerance and the length of time that dead branches persist on a tree, for, as will be shown later, even small dead branches may persist for many years.

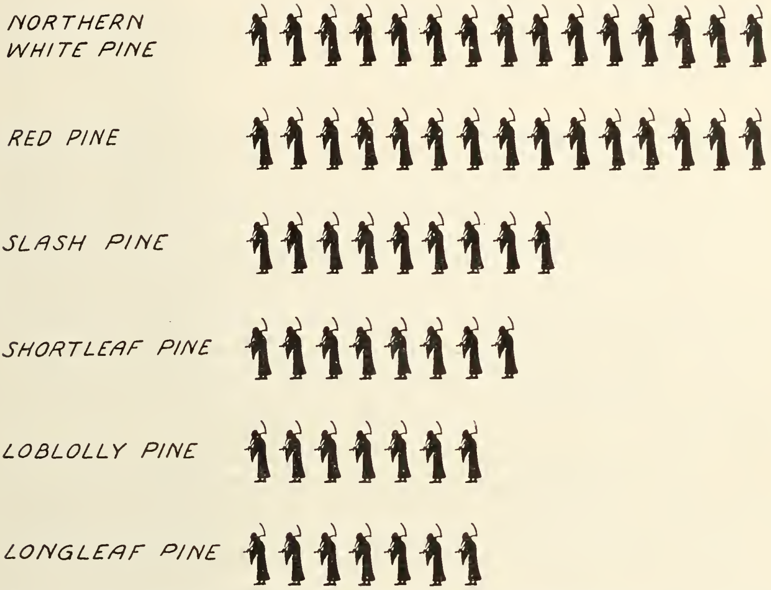

FIGURE 6.—Average number of years lateral branches remained alive in the lower part of the trunk and produced intergrown knots. Each symbol represents 1 year.

The time that branches remained alive in the lower 20 feet of the stem differed markedly among the six species in the stands studied. Lateral branches in both northern white pine and red pine remained alive for an average of 15 years. In loblolly pine and longleaf pine the average was 7 years, in shortleaf pine 8 years, and in slash pine 9 years (fig. 6).

## NATURAL PRUNING

Natural pruning in forest trees comprises the process of the gradual dying of lower branches and finally the separation or disappearance of any protruding portion. A dead branch or branch stub may persist for many years and become after dying the source of even greater degrade of lumber than when alive. Dead branches cause loose, black, or decayed knots, whereas knots from living branches are firmly intergrown and usually less conspicuous in color.

While it is the tolerance of a species that influences the degree of shading necessary to kill the lower branches, it seems to be primarily the resistance of the wood to decay that influences the length of time dead branches persist before they drop off the tree. Factors which it is logical to assume may influence the rapidity of self-pruning are: Inherent resistance to decay, pitchiness, the size of the dead branch, the amount of heart wood, the dryness of the dead branch, fire, and climatic conditions, such as temperature, relative humidity, wind, snow, and sleet.

### ZONES OF A TREE

A mature tree contains three distinct zones with respect to knots which affect the grades of lumber that may be cut from it (fig. 7). The inner zone or core, called the tight-knot zone, consists of the portion of the tree trunk which grew before the contiguous lateral branches died. The second zone consists of the portion of the tree containing encased or loose knots. This zone may be variable in radial thickness, depending upon the rate at which natural pruning has been accomplished. It is situated between the tight-knot zone and the clear-wood zone, provided a clear-wood zone has been formed. The loose-knot zone extends to the bark in that portion of the trunk lying between the upper limit of the clear-wood zone and the base of the green crown.

The clear-wood zone is the most valuable part of the tree for lumber, veneer, and many other uses, although not so important for pulpwood, posts, poles, and fuel. Young trees which have only a relatively thin clear-wood zone have just reached a point where their growth is becoming most profitable and should not be cut until the clear zone is thick enough for advantageous use. In some species the age at which clear wood begins to be formed can be greatly shortened by artificial pruning of the tree trunk, as will be shown later.

### NUMBER OF KNOTS IN A TREE

The total number of branches and hence the number of knots in the trunk of a tree depends both on the number of limbs per node and the distance between the nodes.

#### NUMBER OF KNOTS AS AFFECTED BY BRANCHING CHARACTERISTICS OF SPECIES

Within certain limits the number of knots per node reflects branching habits of the species and is therefore characteristic of it. Of the six species studied, northern white pine produced the greatest number of branches per node and the greatest number of nodes with more than five branches each. Red pine came second in the number of branches at a node. In the southern pines usually two to four branches occurred at each node and the percentage of nodes having more than five branches was negligible.

Only in the southern pines did the number of knots in different stands of the same species appear to be influenced by stand conditions. Where loblolly and shortleaf pines were growing in mixture with hardwoods the reduction in the number of knots in the first 20 feet ranged from 15 to 25 percent. In longleaf pine the denser stands also contained fewer knots (table 1).

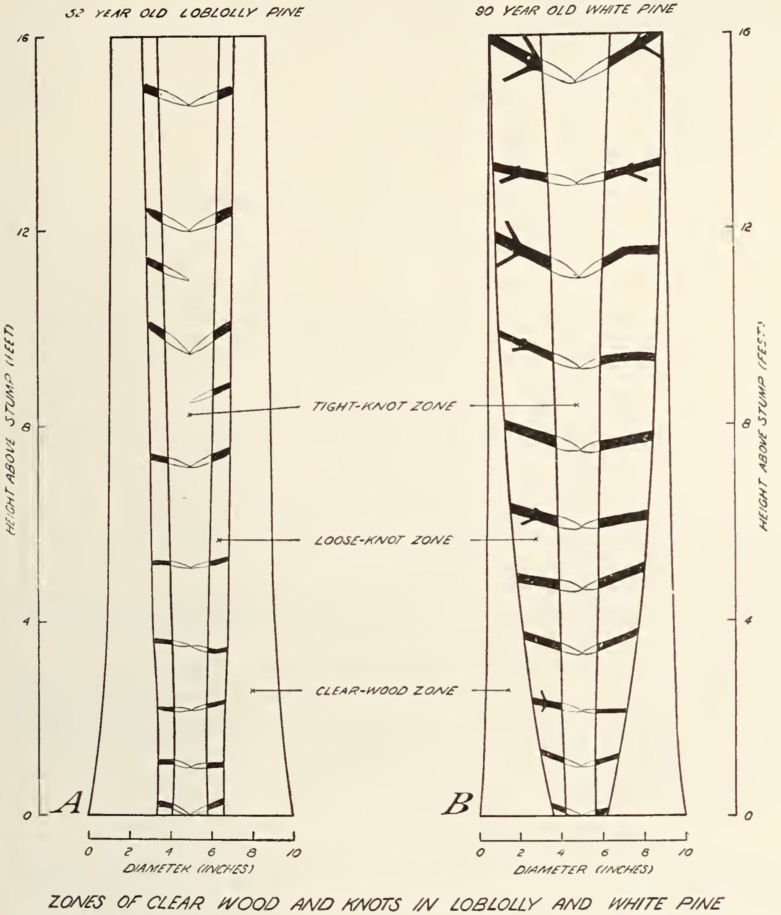

FIGURE 7.—Zones of clear wood and knots in loblolly and northern white pines: *A*, In 52-year-old loblolly; *B*, in 90-year-old white pine.

The average number of knots in the lower 20 feet for the species studied is shown diagrammatically in figure 8.

### NUMBER OF KNOTS AS AFFECTED BY ANNUAL HEIGHT GROWTH OF THE TREE

In species like northern white and red pines, which as a rule branch only at the terminal nodes, the number of knots depends primarily on the site quality, the density of the stand, and other external factors influencing the annual growth in height of trees. Thus a tree with many branches per node that has made rapid growth in height may contain fewer knots per unit length than a tree with few branches per node that has grown more slowly in height.

In the southern pines, branches are developed not only at the annual terminus of the leading shoot, but also at intermediate points along the season's growth. In the same growing season, several branch nodes instead of one may be formed. The total number of branches per unit length of bole in the southern pines is therefore not consistently influenced by the rate of growth of the trees in height. Rate of growth itself also does not materially affect the number of branches per whorl.

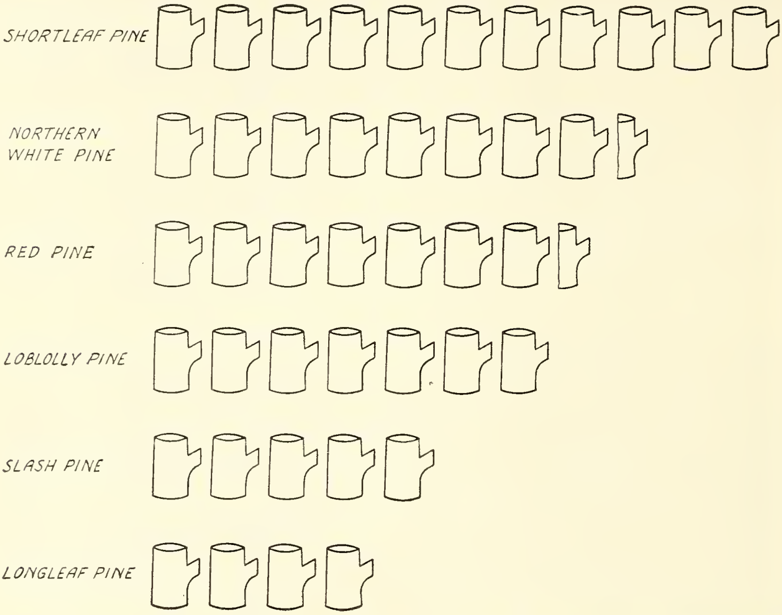

FIGURE 8.—Average number of knots in first 20 feet above stump. Each complete symbol represents 10 knots.

## NUMBER OF KNOTS AS AFFECTED BY HEIGHT IN TREE

No definite correlation was found in the number of knots per node and the position of a node in the first 20 feet of the trunk with the exception that the lower two to four nodes in red and northern white pines frequently contained fewer knots than the succeeding ones. In the southern pines the average number of branches per node is practically constant throughout the lower 20-foot length of a tree.

## SIZE OF KNOTS

The maximum diameter of a knot depends upon the time the branch from which the knot is formed remains alive and on the rate of growth of the branch; the length of a knot depends on a number of factors, chief of which is where the branch broke off, if close to the trunk or some distance from it.

The diameters of all knots in this study were measured at right angles to the branch axis at the outer end of the intergrown portion as indicated in figure 2, line *ab*.

### RANGE IN DIAMETERS OF KNOTS

The knots were grouped according to size into three classes: (1) Knots with diameters of 0.5 inch or less; (2) knots over 0.5 and including 1.0 inch in diameter; (3) knots with a diameter in excess of 1 inch. Figure 9 depicts the range and average diameters of knots in the 20-foot butt log of the different species under consideration. Figure 10 shows the percentage of knots in each class for the six species examined.

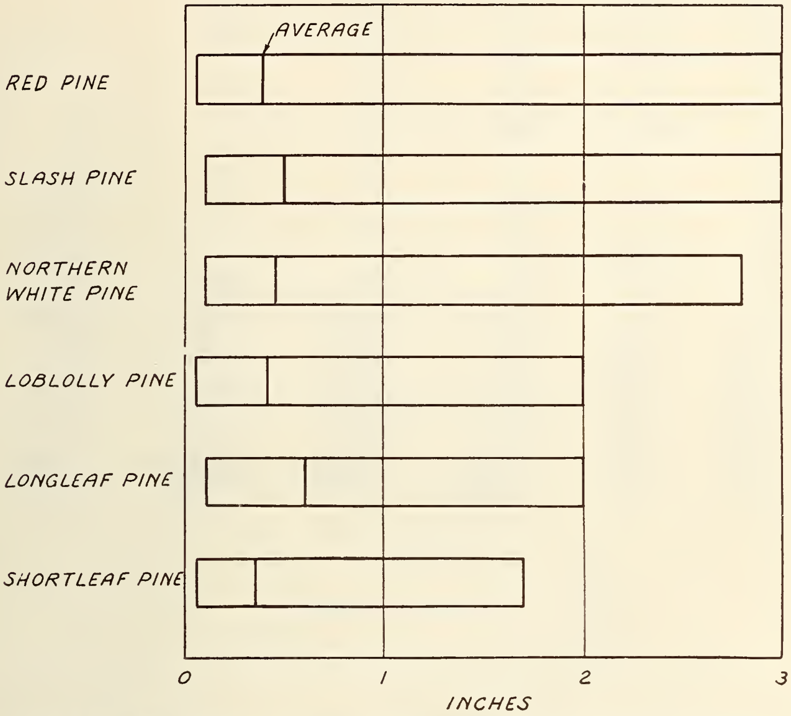

FIGURE 9.—Ranges in diameters and average diameters of knots in first 20 feet above the stump.

### DIAMETERS OF KNOTS AS AFFECTED BY HEIGHT IN THE TREE

The average diameter of knots in successive nodes from the ground to a height of 20 feet was found to increase in all species. This increase was more rapid in the first 12 to 16 feet, slowing up considerably but not necessarily tending to constancy thereafter. The greater thickness of branches, higher in the tree, is more noticeable in the less tolerant southern pines.

### EFFECT OF STAND DENSITY ON DIAMETER OF KNOTS

The influence of stand density upon the diameter of knots did not exhibit itself strikingly in the different stands of the same species, except in two cases. In northern white pine stands with 450 and with 1,080 trees per acre, 64.3 and 72.5 percent, respectively, of the knots had diameters of one-half inch or less. Red pine from the same areas (stands Nos. 5 and 6, table 1) showed practically no difference in the size of knots but in a stand with 400 trees per acre (stand No. 8), characterized by slow diameter growth of the trees, red pine had 20 percent more knots in the smallest class than in the foregoing stand with 1,080 trees per acre.

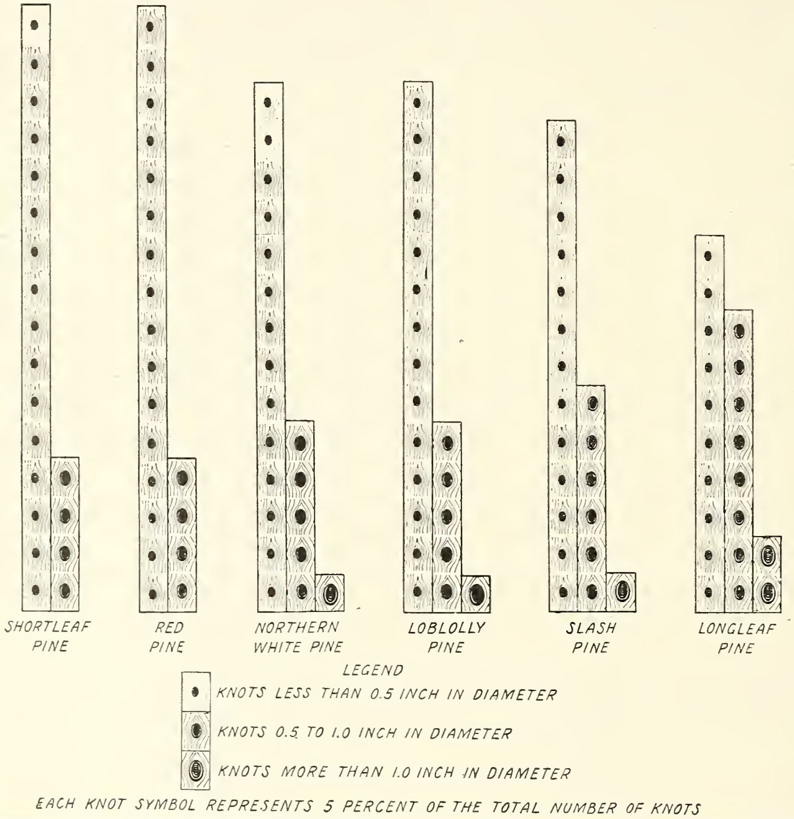

FIGURE 10.—Percentage of total number of knots in lower 20 feet of stem appearing in each diameter class for six species of pine. Each knot symbol represents 5 percent of the total number of knots.

In longleaf pine stands in Mississippi with 350 and with 530 trees per acre, the differences in the number of knots in each classification is shown in table 2.

TABLE 2.—*Knots in longleaf pine stands in Mississippi*

| Class (inches) | Stand with 350 trees per acre | Stand with 530 trees per acre |
|---|---|---|
| | *Percent* | *Percent* |
| 0 to 0.5 | 45.5 | 76.6 |
| 0.6 to 1.0 | 48.7 | 22.8 |
| 1.1 and over | 5.8 | .6 |

It appeared from conditions in the forest that the stand with 530 trees per acre may have been even more densely stocked earlier. The trees were of smaller diameter than those in the stand with 350 trees per acre and stood in small irregular groups, an indication that intervening spaces may have been cleared by forest fires. A longleaf pine stand in Florida with 480 trees per acre produced more knots in the larger size classes than did either of the Mississippi stands.

Differences of 5 to 14 percent in the proportion of knots in the various size classes were found between pure pine stands and stands with hardwoods in mixture in loblolly, shortleaf, and slash pines.

Tarbox and Reed (*10*)[3] report a consistent decrease in average knot diameter of dead knots in northern white pine with increasing number of trees per acre in the 20- to 30-year age class. Their data show that increasing the number of trees from 500 to 2,000 per acre served to reduce the average knot diameter from 0.79 to 0.43 inches.

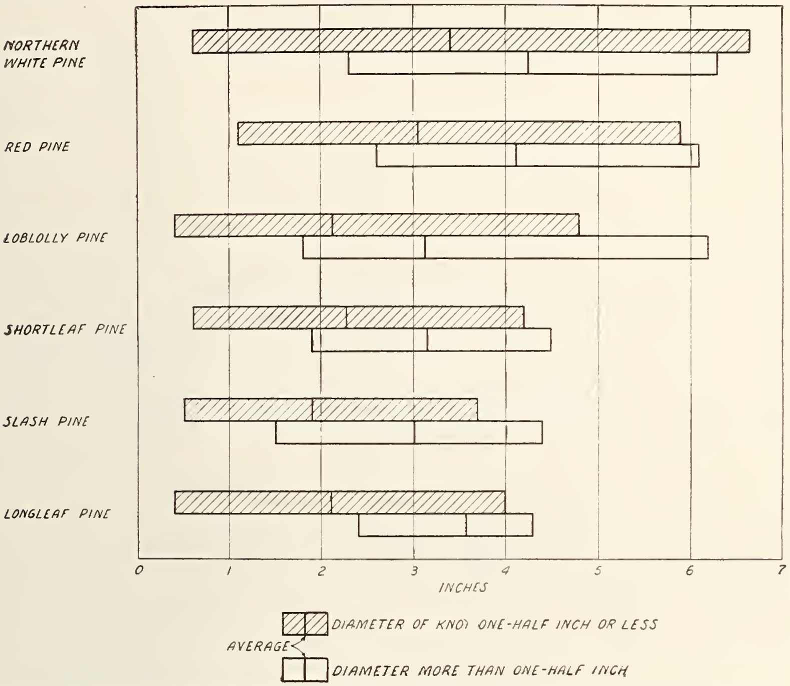

FIGURE 11.—Range and average total length of occluded knots, by diameter classes, in first 20 feet above stump.

RANGE IN THE LENGTHS OF KNOTS

The total length of an overgrown knot in the trunk of a tree depends upon two things, (1) its growth during the time that the branch remained alive during which the knot is intergrown, and (2) the length of the dead stub finally completely surrounded and overgrown by the increasing thickness of the trunk. The range in length of knots of different sizes in the six species is shown in figure 11.

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[3] Italic numbers in parentheses refer to Literature Cited, p. 35.

The length of the intergrown portion of any branch included within the stem of a tree is influenced primarily by the tolerance of the species, shading from the side, and conditions external to the tree which influence the rate of growth. In sparsely stocked stands the tolerance of the species does not at first come into play and the lower lateral branches remain alive often for many years until surrounding trees have attained sufficient size to shade them. The associated trees in a stand and the density of their foliage may have an important influence upon the time that side branches of the less tolerant species remain alive. The stands studied did not reveal much difference in the average length of the intergrown branch portions but in the same stand the intergrown portion of branches of small diameter averaged considerably shorter than that of the larger branches, indicating an average earlier death of the small branches (fig. 12). The intergrown branches of the smallest diameter class averaged somewhat greater in length in northern white pine and red pine than in the southern pines, probably due to greater tolerance of these species. In the

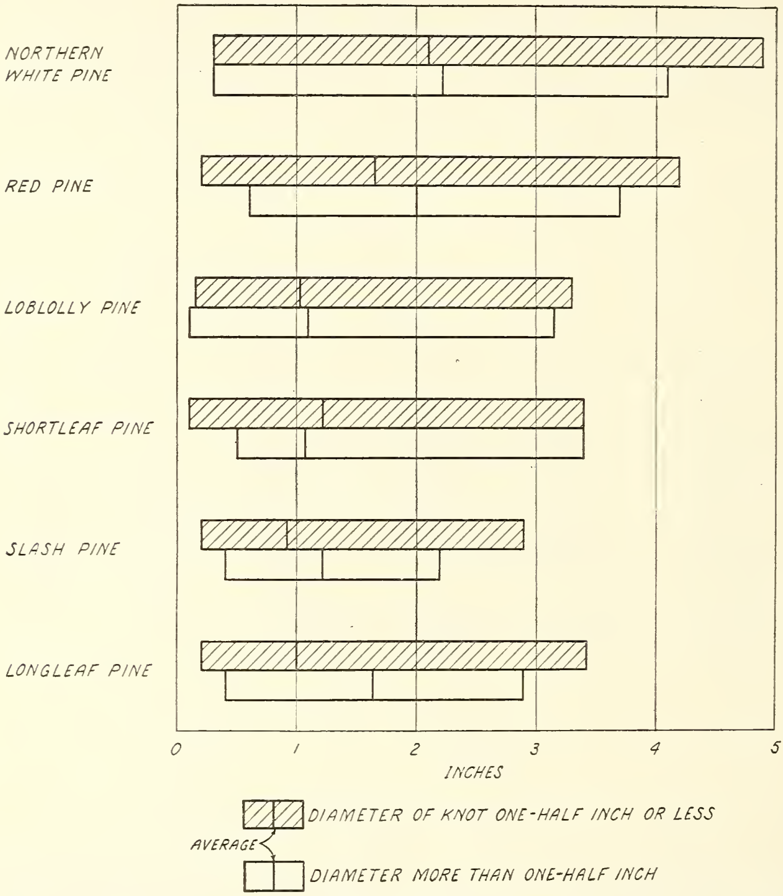

FIGURE 12.—Range and average length of live portion of occluded knots, by diameter classes, in first 20 feet above stump.

larger diameter class the average length of the intergrown portion was nearly equal in all species except slash pine in which it averaged slightly shorter.

A tree that grows rapidly when young will have a greater proportion of its volume occupied by live knots than a tree that grows slowly. Conditions that cause trees to grow slowly, as a rule, are conducive to the early death of the lower branches so that in slow-growing trees the live portion is shorter and the total amount of wood containing knots is smaller.

The length of the black or "dead" portion of a knot depends upon (1) the time that the dead branch remains attached to the tree and (2) the closeness to the stem at which the branch breaks off. Branches do not at once drop to the ground following the death of their foliage. Even after death they may remain intact until drying has caused the wood of the branch to shrink and the bark to loosen and fall. After this the branch becomes still further weakened by agents of decay before it finally breaks off. The actual breaking of a weakened branch may, of course, be hastened by external conditions, such as wind, rain, snow, and ice.

### RELATION OF DIAMETER TO LENGTH OF DEAD KNOTS

The average length of dead knots in the smallest diameter class nearly equaled or exceeded that of the larger knots in northern white, loblolly, and shortleaf pines while in the other three species the average length of the smaller dead knots was considerably below that of the larger ones. The maximum length of small dead knots, however, exceeded the maximum length of larger knots in five species and equaled that of the larger knots in the sixth (fig. 13). In general no definite correlation of diameter and length of the dead knots studied could be found.

### LENGTH OF TIME DEAD BRANCHES PERSIST

As long as dead limbs or their stubs extend through the bark their incorporation in the trunk of the tree continues and the formation of clear lumber is delayed. Dead branches that have become thoroughly dry do not readily fall off the tree. They are the source of encased, loose, and decayed knots which cause greater degrade in lumber than intergrown knots from living branches.

In northern white and red pines, dead branches or their stubs were found to persist much longer than in the southern pines. The average length of time that overgrown dead branches in the first 20 feet of these species persisted was 27 years for northern white and 24 years for red pine (fig. 14). There were many other instances where dead branches persisted for long periods. The maximum recorded for the trees investigated was 73 years in northern white pine and 67 years in red pine, both in an 86-year-old stand. In slow-growing trees, however, the long persistence of dead branches is not so serious from the standpoint of volume production of clear wood as in faster growing ones. For example, if a dead branch persisted for 20 years on a tree that grew 1 inch in radius in 20 years then there would be only 1 inch of loose knotted wood formed, but on a tree which grew 5 inches in radius in 20 years there would be 5 inches of loose knotted material.

Therefore, the rapid removal of dead branches is increasingly important as the length of rotation is shortened for timbers of a given size.

Among the southern pines, dead branches persisted for the longest time in shortleaf pine for which the average was 12 years, followed by an average of 8 years in loblolly and 6 years each in slash and longleaf pines. The maximum number of years of persistence recorded for dead branches in the first 20 feet were 49 for loblolly, 41 for shortleaf, 20 for slash, and 17 for longleaf pine.

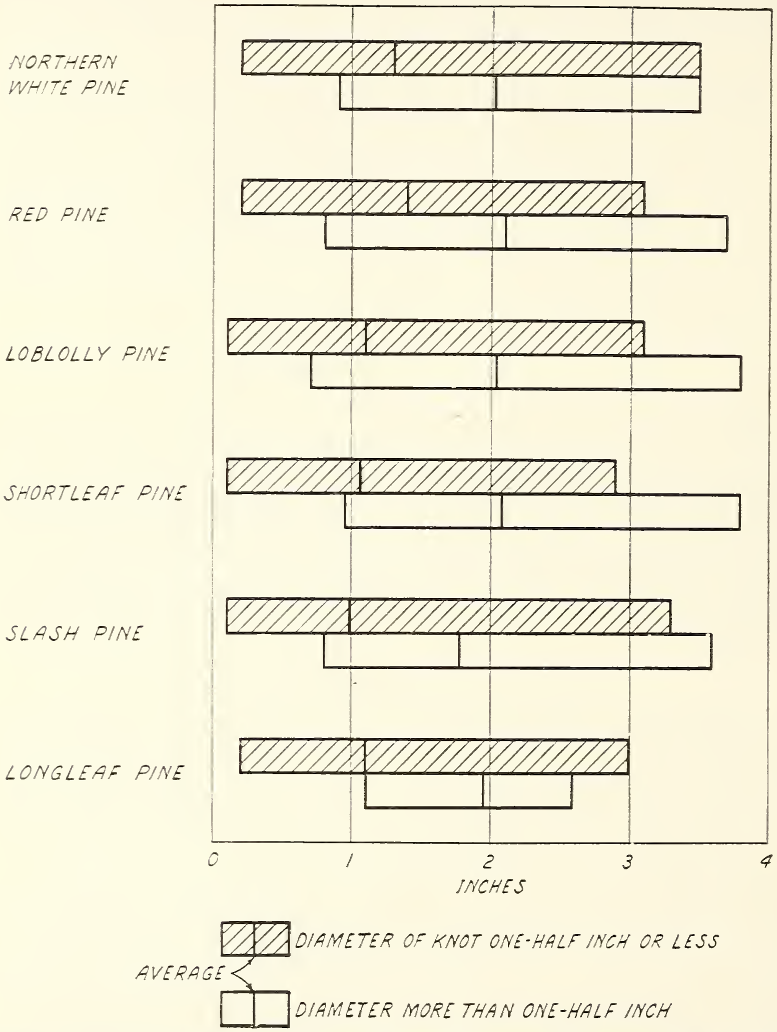

FIGURE 13.—Range and average length of dead portion of occluded knots, by diameter classes, in first 20 feet above stump.

The length of time elapsing between the death of a branch and its final sloughing off appeared to depend neither upon the diameter nor the age of the branch. Younger and thinner branches (less than 0.5 inch in diameter) actually persisted as long, and sometimes even longer than did older limbs of greater diameters, a fact that emphasizes the importance of early pruning in order to produce a maximum of clear wood.

The rapidity with which dead branches are shed appeared to be dependent upon climatic, silvicultural, and inherent factors.

### INFLUENCE OF CLIMATIC FACTORS

High humidity together with high temperatures for long periods each year produce a damp condition in the dead branch wood that is favorable to decay. The more rapid shedding of side branches by the southern pines than by the pines of the Northern States is undoubtedly partly due to the more humid atmospheric conditions and longer summer seasons in the South.

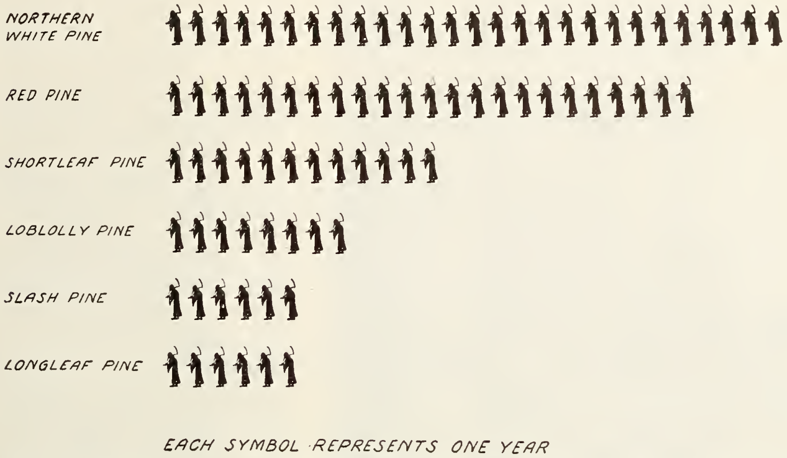

FIGURE 14.—Average number of years dead branches or stubs persisted and produced encased knots. Each symbol represents 1 year.

### INFLUENCE OF SILVICULTURAL FACTORS

Close spacing of trees during the early life of forest stands hastens the death of the lower branches, resulting in knots of somewhat smaller diameter than in less crowded stands. Close spacing also reduces the diameter increment of the trees and lengthens the time required for them to attain merchantable size.

Close spacing, however, does not materially influence the falling of dead branches in pure stands of a species like northern white pine (fig. 15). Hawley and Clapp (*7*) state that "with white pine, especially, stand density has but little bearing upon natural pruning" and that "branches persist upon the trees for so long that practically no natural pruning is attained for many years." Deen (*5*) cites a case of abandoned nursery seedbeds near Keene, N. H., where trees originating from seed sown 25 years ago have been allowed to grow undisturbed. The density was approximately 23,000 trees per acre, and the average size of dominant trees about 16.5 feet in height and 2.3 inches in diameter. The average height to the first living branches was approximately 8 feet, but dead limbs persisted even in this density to within 18 inches of the ground. How much longer they will persist only time can tell. Therefore, the most apparent effect of close spacing in northern white pine is the earlier death of green branches, not their earlier disappearance.

As has been shown, overcrowding sufficient to retard branch development in dense stands also decreases the volumetric increment of the individual trees. In a short rotation this serious disadvantage more than offsets the slight benefits gained by closer stocking.

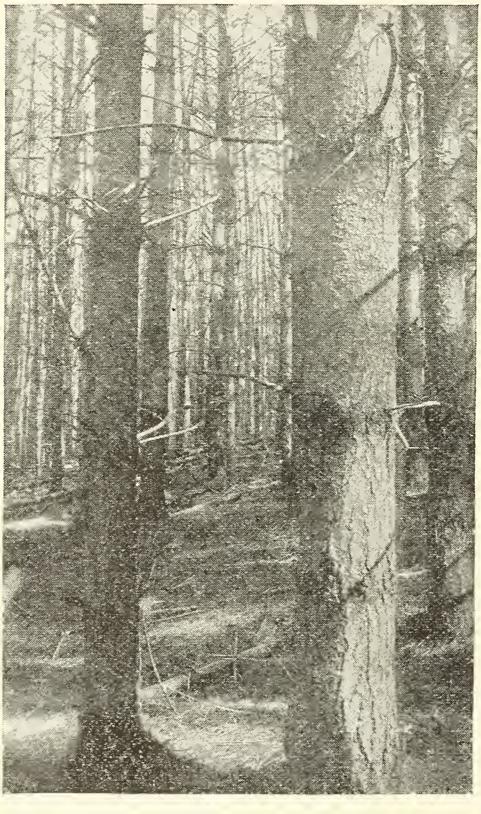

FIGURE 15.—A 33-year-old plantation of northern white pine in which the trees originally were planted 2,700 to the acre with 2½- by 6-foot spacing. Clear wood has not yet begun to form despite the fact that the lateral branches have been dead for a long time.

In the southern pines a fairly uniform distribution of hardwoods in a stand caused the branches of the pine to die sooner and the dead branches to fall more quickly than in pure stands (fig. 16). This is in conformity with the results obtained by the Forest Products Laboratory in a study of lumber grades in which the grades of lumber obtained from pines growing in mixture with hardwoods showed a decided increase in the percentage yields of high-quality lumber with increase in the proportion of hardwoods (*9*). In shortleaf, slash, and loblolly pines the intergrown and encased portions of knots were shorter and comparable trees had longer clear length in stands where broadleaved trees were well mixed with the pines.

Broadleaved species in mixture with pines influence natural pruning in at least two ways: (1) Heavier shade of broadleaved trees deprives the side branches of sunlight and hastens the death of the branches; (2) under the heavy shade of hardwoods the moisture content of the dead branches remains higher, thus creating a condition more favorable to the progress of decay.

### INHERENT FACTORS

A somewhat slower rate of natural pruning in northern white pine than in red pine may be attributed to inherent differences in the species, particularly since trees of the two species when growing side by side show considerable difference in clearness of the lower part of the stem (fig. 17). Similarly in the southern pines, loblolly and slash show greater inherent tendencies for natural pruning than longleaf and shortleaf.

Because of the wide differences in climatic conditions between the Northern and Southern States, it is difficult to say how much credit for the faster natural pruning of the southern species when compared with the northern species is attributable to climatic conditions and how much to inherent characteristics of the species.

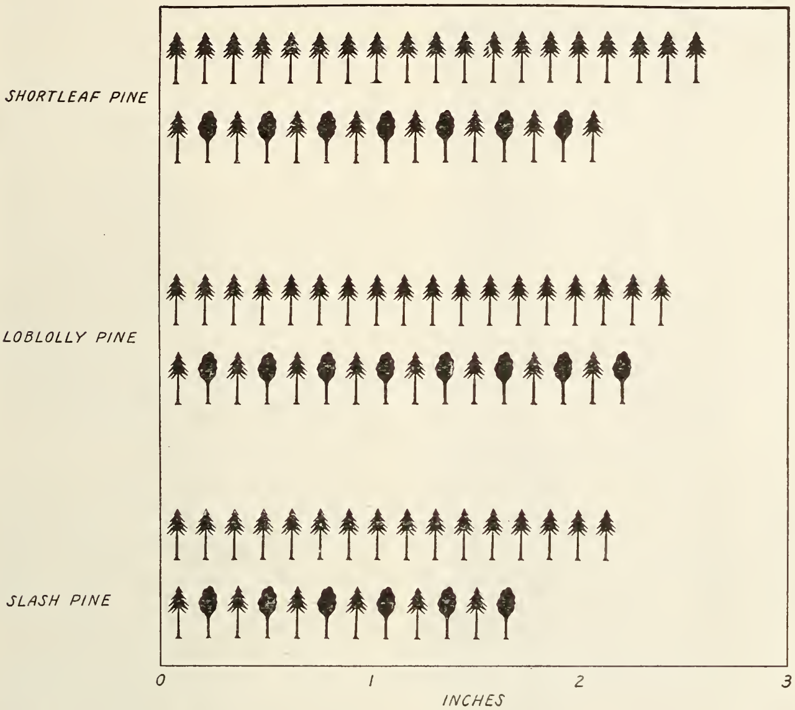

FIGURE 16.—Comparison of average length of occluded knots in pure and in mixed stands. For each species the upper row represents a pure stand and the lower row a mixed stand.

### OTHER FACTORS

It has already been shown that branches of small diameter often persist longer than larger ones of the same species. Certain of these branches (fig. 18) persist for many years independent of spacing, composition of the stand, or climatic conditions. In the southern pines dead branches less than one-half inch in diameter have been found to persist for nearly 50 years. In red and northern white pines such branches have persisted much longer. The continuation of small branches for so many years can probably be attributed to the high degree of dryness of the branches. Branches of small diameter dry so quickly that the moisture content soon becomes too low to support the growth of wood-destroying fungi. In all the species studied the dead branch showing the maximum number of years of persistence was from the smallest diameter classification, namely, less than one-half inch.

When dead branches of adjoining trees interlock the initial breaking of a decaying branch may be delayed and may not at first result in its removal. Frequently after breaking, the outer end of the branch is supported from falling by other branches of the same or adjoining trees and sometimes remains in its original position for several years before a second break occurs. During this time the basal end of the branch continues to be surrounded by the increasing growth of the trunk of the tree, the same as if the branch were still intact. An occurrence of this action twice in a loblolly pine branch is shown in figure 19. Another thing which sometimes happens to delay the occlusion of a branch stub is the accumulation of pitch in a cross break of a branch and a gradual outward movement of the loose end as the accumulating pitch mass increases (fig. 20).

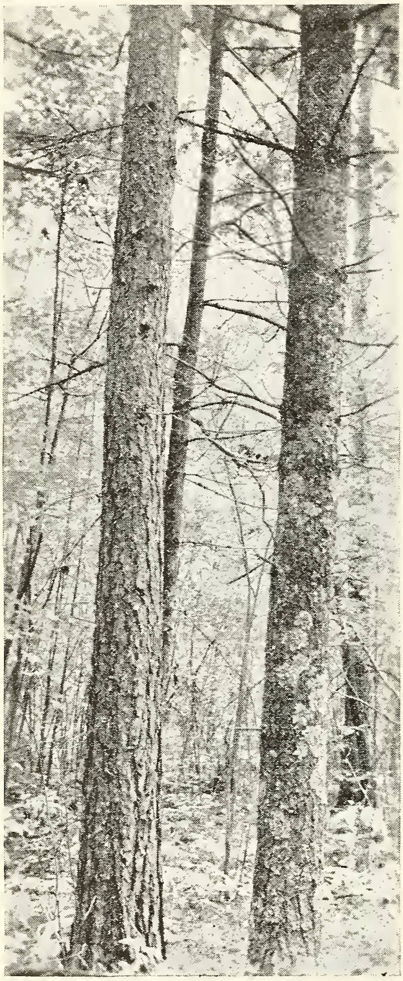

FIGURE 17.—Comparison of natural pruning of red pine (left) and northern white pine (right) in a 56-year-old stand. The persistence of the branches on the northern white pine will prohibit the formation of clear lumber for many years.

### PROTECTIVE LAYERS IN DEAD BRANCHES

Mayer-Wegelin (*8*) has stressed the natural ability of certain species to form protective layers at the base of dead branches. Such layers prevent the entrance of decay into the trunk of the tree through the exposed wood of a dead branch. In the pines there is often an accumulation of resin which forms a protective zone against the entrance of fungi at the base of the dead branch (fig. 21).

### FORMATION OF CLEAR WOOD

When the diameter of the trunk has grown outward as far as the ends of broken branches, the growth rings push over the edges of the broken surface and soon cover it. In this process bark or pitch sometimes becomes occluded at the end of the stub, preventing the immediate formation of clear wood. Usually such accumulations are not serious unless the branch stubs are very large or an unusually large amount of pitch accumulates. Often there is a swelling at the node which causes a deviation of the growth rings even after the knots are completely covered. When the gap over the branch stub has been completely bridged the formation of successive layers of clear wood proceeds year after year without further interruption. A comparison of the rate of natural pruning in four of the six species studied is shown in figure 22. In longleaf pine natural pruning was found to proceed at about the same rate as in shortleaf pine; slash pine at about the same rate as in loblolly pine.

It is evident from the foregoing data on knots that clear lumber will not ordinarily be obtained from second-growth stands of northern white pine or red pine less than 80 years of age. In the southern pines under conditions of high stand density natural pruning to a height of 20 feet takes place in 6 to 15 years after the branches die. However, in the usual understocked second-growth stands of southern pine, which prevail over extensive areas, the production of clear lumber by natural processes must be awaited for many years—just as in our virgin forests the high-grade product followed a long preparatory period of natural pruning often beginning at an age equal to or greater than the age of many second-growth stands now being cut into lumber.

## ARTIFICIAL PRUNING

Results of artificial pruning were studied in nine northern white pine trees (fig. 23) and six red pine trees from a second-growth stand in New Hampshire[4] pruned 40 years ago when the trees were 3 to 4 inches in diameter and again about 15 years later (fig. 24). In the first pruning, branches were removed to a height of about 6 feet, evidently with an ax. The overgrown stubs when cut open for study indicated that most of the branches were living when removed as the dead portion of the knot was usually only about one-fourth of an inch long. These short black ends doubtlessly represent projections left in pruning. The branches cut off in the first pruning operation averaged only one-half inch in diameter in both species.

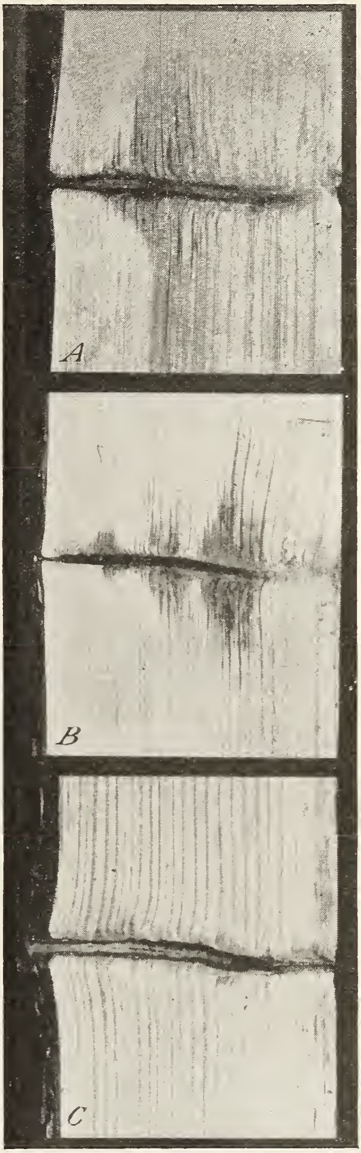

FIGURE 18.—Persistence of small dead branches in (*A*) northern white pine, (*B*) red pine, and (*C*) short-leaf pine. These examples refute the opinion of many timber growers that close spacing results in the formation of clear lumber.

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[4] The trees were obtained from O. M. Pratt, Holderness, N. H. The Northeastern Forest Experiment Station, New Haven, Conn., selected the trees.

The second pruning extended to a total height of 12 feet. In this pruning operation the branches were cut off with a saw attached to a pole.

The branches removed in the second pruning had been dead for several years. Both the intergrown and dead portions of the occluded

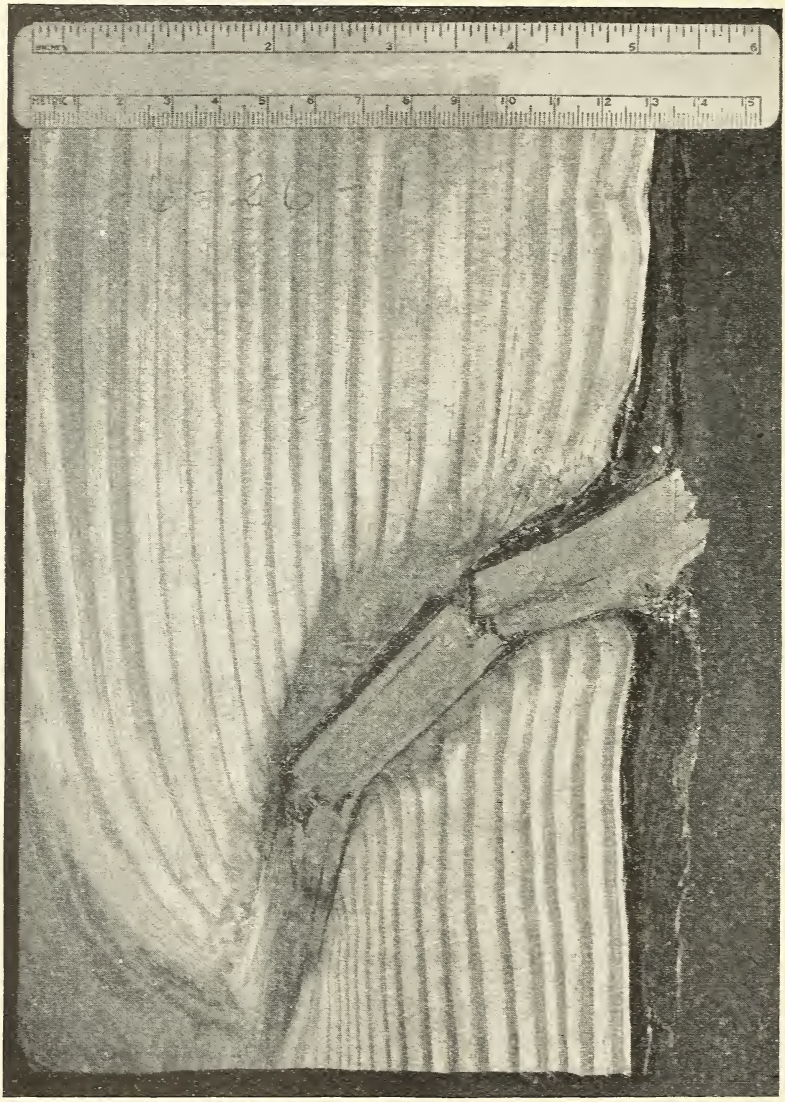

FIGURE 19.—Broken dead limbs, supported by adjacent trees, may continue to become encased within the trunk as shown in this loblolly pine.

branch stubs were longer and thicker than in the branches pruned earlier. In this section of the trunk the average diameter of the knots was 0.7 inch; the length of the dead portion averaged three-quarters of an inch (fig. 25).

### PRUNING DEFECTS

An examination of 646 pruned knots in the two species showed no evidence that decay had entered as a result of pruning. In the northern white pine decay was found in none of the knots of the earlier pruning and in only 11 of the second pruning. In the red pine decay was found in seven knots of the first pruning operation and in 19 of the second. The indications are that all knots showing decay were from branches that were dead prior to pruning. This is surely true of those from the second stage of pruning. Even when pruned knots themselves contained decay, no case was found where it had spread from the knots into the trunk of the tree.

Pitch accumulations and bark inclusions after pruning were not of serious proportions and usually were soon covered over unless careless pruning had resulted in irregular and uneven wound surfaces. Cline and Fletcher (*2*) and other investigators[5] state

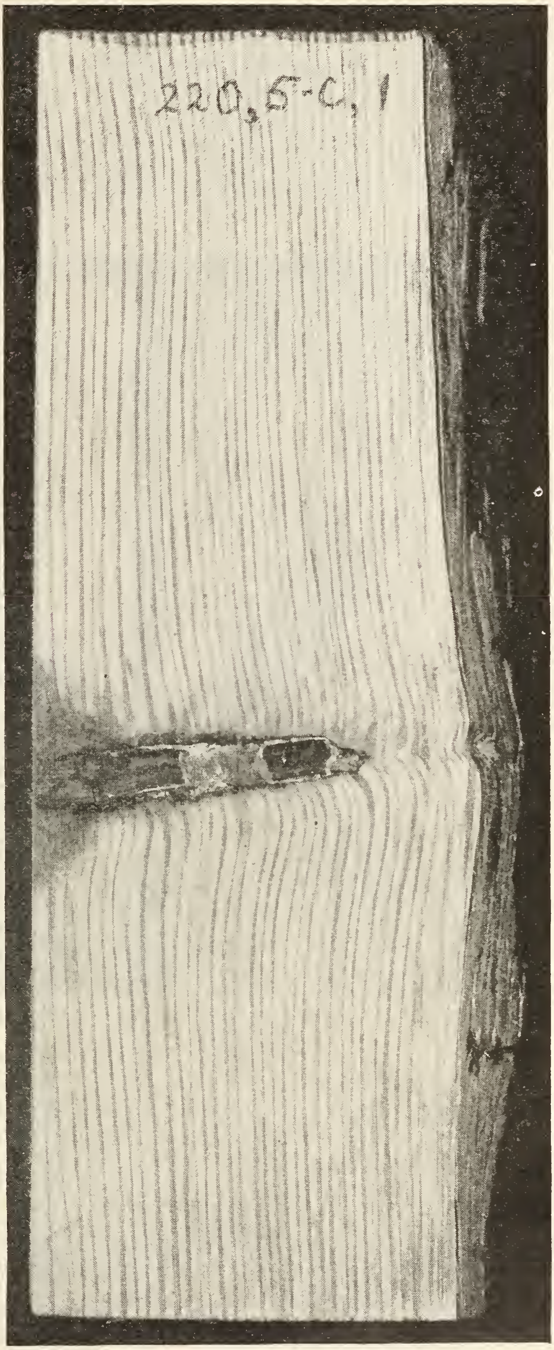

FIGURE 20.—Formation of a pitch plug behind the broken end of branch delayed occlusion by pushing the loose end outward in this shortleaf pine.

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[5] Spaulding, P., MacAloney, H. J., Cline, A. C. STEREUM SANGUINOLENTUM A DANGEROUS FUNGUS IN PRUNING WOUNDS ON NORTHERN WHITE PINE. Tech. note 19, Northeastern Forest Experiment Station, 2 p., [Mimeo.]

that the greatest danger of the entrance of decay into the tree from pruning wounds is in the removal of large green branches in which the heartwood is comparatively dry, but that in the case of small branches, whether living or dead, there is little danger of infection.

### TIME REQUIRED FOR GROWING OVER OF PRUNED BRANCHES

The time required for the cut surface of a pruned branch to grow over depends upon several factors outside of the branch itself. To be sure, small branches if cut close to the trunk will grow over more quickly than large ones. In branches of any size projecting stubs delay the covering over of the cut end of the branch (fig. 26). The trunk must increase in size until the stub is surrounded before the growth layers will begin to grow across the cut face. In the pines a stub soon dies and then acts the same as a dead branch. Irregularities left in cutting branches delay healing. Examples of satisfactory and unsatisfactory healing of pruning wounds appear in figure 27.

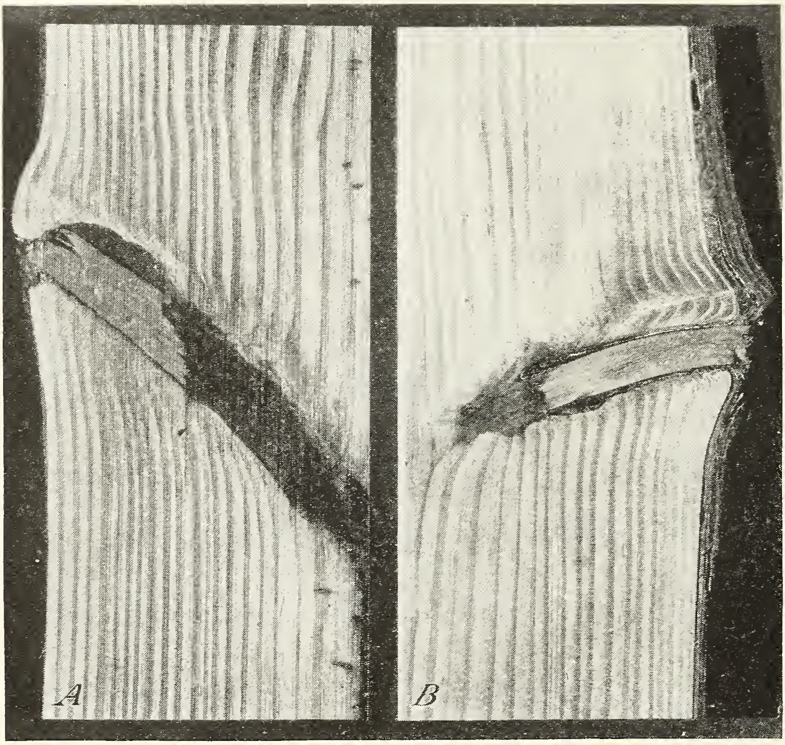
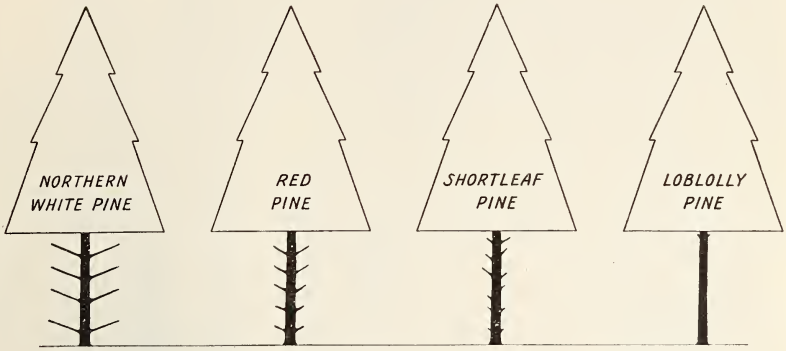
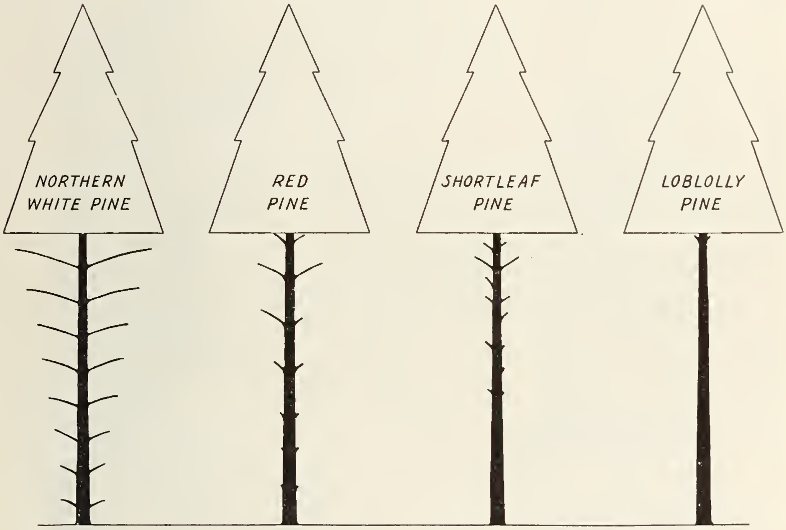


FIGURE 21.—Protective zones formed at the bases of dead branches by the infiltration of pitch: *A*, Slash pine; *B*, loblolly pine.

In the trees studied the time required for the cut ends of the branches in the first pruning to heal over averaged 3 years for northern white pine and 5 years for red pine. The total time elapsing between the actual cutting of the branch and the covering over of the surface is influenced by the length of the stub and the thickness of the annual growth layers of the trees. Because of the large size of the branches



NATURAL PRUNING AT 25 YEARS



NATURAL PRUNING AT 50 YEARS

FIGURE 22.—Progress made in natural pruning by four species of pine at 25 and 50 years of age. Clear length at 25 years, northern white pine, 0 feet; red pine, 0 feet; shortleaf pine, 0 feet; loblolly pine, 12 feet; clear length at 50 years, northern white pine, 0 feet; red pine, 3 feet; shortleaf pine, 14 feet; loblolly pine, 37 feet. The rate of pruning of longleaf and slash pines was approximately the same at the 25-year age as that of shortleaf and loblolly, respectively.

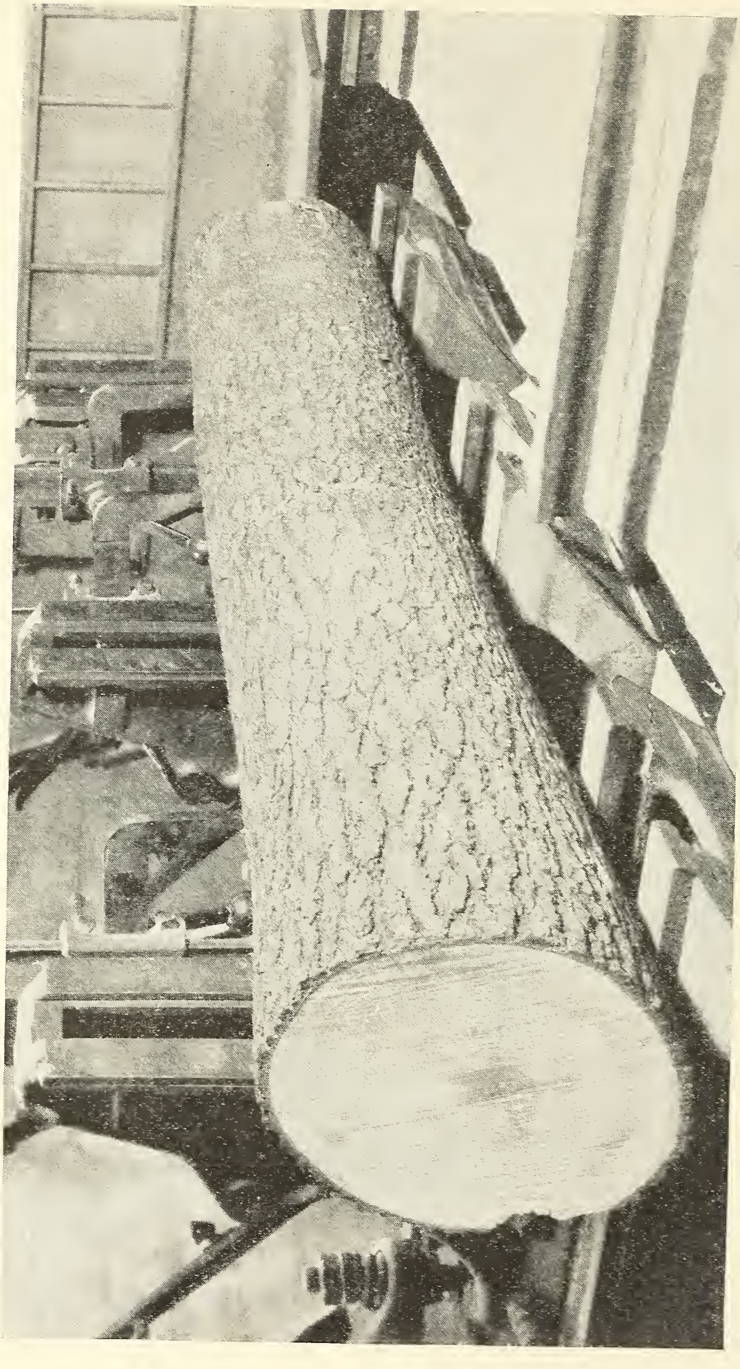


FIGURE 23.—Pruned trees mean clear lumber. This log came from a stand of northern white pine pruned many years ago.

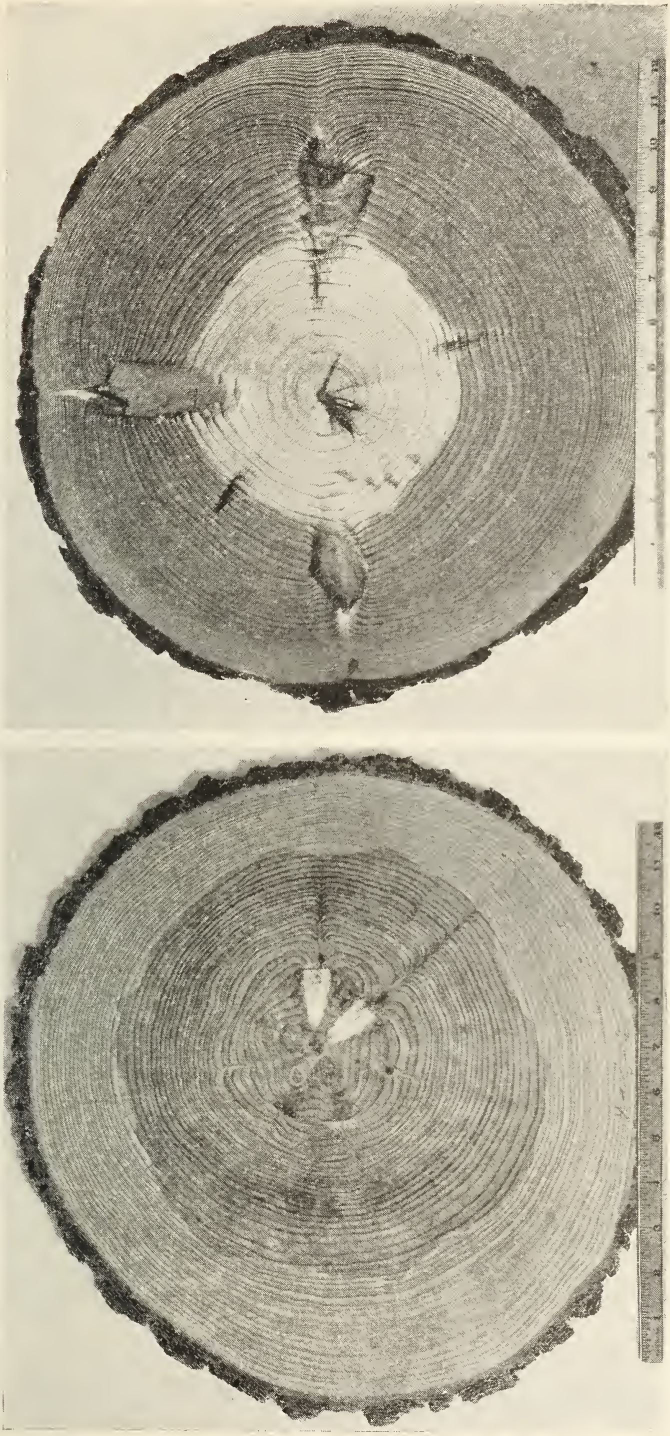


FIGURE 24.—Cross sections through nodes of northern white pine pruned 40 years ago (left) and 25 years ago (right).

the growing over of the branch ends in the second pruning required an average of 2 years longer than those of the first pruning, namely, 5 years for northern white pine and 7 years for red pine. The length of stubs left in the second pruning is unknown because the branches were already dead when the pruning was done.

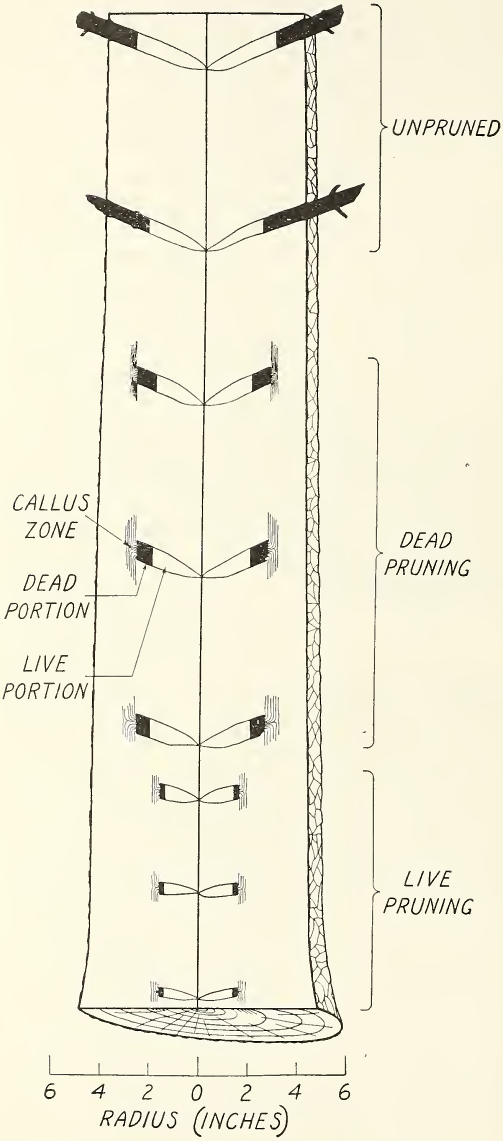


Figure 25.—Drawing based on composite values from measurements of eight northern white pine trees, the basal portion of which was pruned 40 years ago and the next higher portion about 15 years later. Half of the nodes in a vertical length of 17 feet are shown.

Experiments reported by Anderson (*1*) in England, by Curtis (*4*) in Massachusetts, and Mayer-Wegelin (*8*) in Germany show that in pruning dead branches, more rapid healing will result if the cut is made close enough to the trunk of the tree to wound the living cambium at the branch node in order to stimulate the immediate healing over of the wound. In applying this principle to the removal of living branches the cut must be made well into the collar at the base of the branch so that no projecting dead stub will be left to delay healing over of the cut surface.

Factors which influence the time required for healing of pruning wounds for a knot of a given size are rate of diameter increase, the closeness and smoothness of the cut, and the season of the year that the pruning is done. Anderson (*1*) found in Douglas fir that wounds from living branches one-half to three-fourths inch in diameter pruned close to the trunk of the tree in February healed before autumn of the same year, but the branches pruned in later months did not heal so rapidly.

Hawley and Clapp (*7*) report that 10 years or more, depending upon size, are required to heal over pruned branch stubs in a plantation of northern white pine spaced 6 by 6 feet. With wider spacing of the trees or by thinning the stand at the time of pruning or before, it appears likely that the progress of healing might have been accelerated. Donald (*6*) says the rate of growth of the tree at the time of and immediately subsequent to pruning appears to be of the greatest importance in securing speedy occlusion. However, it is not so much rapid healing that is of importance in conifers as it is closeness of cut of the branches and rapid increment in general thereafter so as to produce a large volume of clear wood in a short time.

### CLEAR LUMBER FROM PRUNED TREES

Figure 25, which is based on the data from eight of the pruned northern white pine trees, shows a distinct advantage in amount of clear lumber obtainable as a result of early pruning over that of the deferred second pruning. The longer and larger intergrown and dead knots, which were formed before the second pruning, entail a loss of 2 to 3 radial inches of clear lumber per tree. In this stand the pruning should have been continued upward at a much shorter interval, within 4 or 5 years at most. The delay also caused some disadvantage to the earlier pruning by restricting the length of some of the clear boards in the lower section to lengths shorter than usual lumber standards.

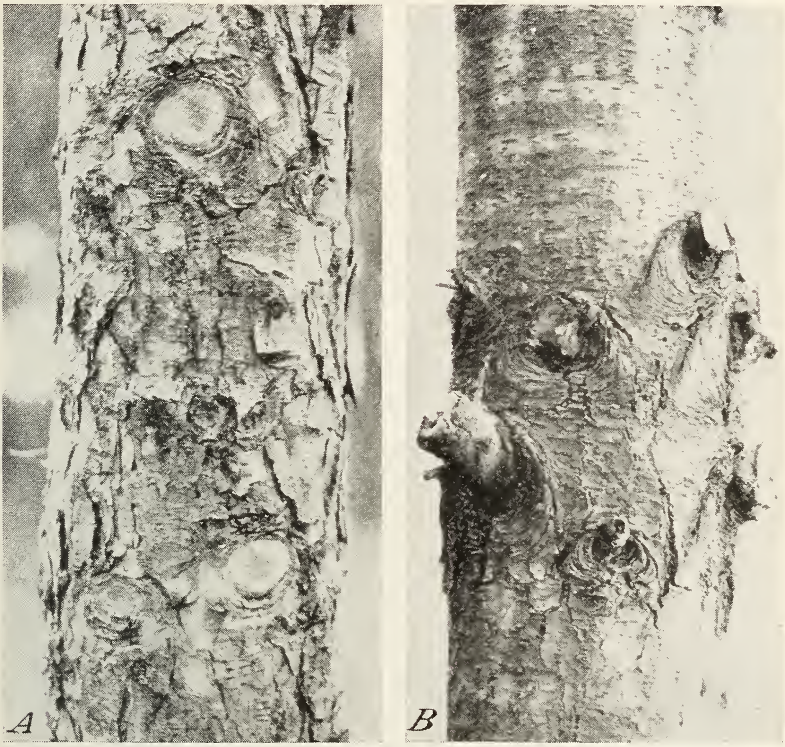


FIGURE 26.—Good and bad pruning practices: *A*, Branches were cut close to the trunk; *B*, protruding stubs were left.

The possibility of securing wide clear boards as a result of early pruning in red and northern white pines is illustrated in figure 28. Lumber cut from the first pruned section of northern white pine trees pruned 40 years before felling had 90 percent of the lumber entirely clear of knots.

The spread in price between clear and common grades varies considerably from time to time, depending upon supply and demand. Roughly the lower clear grade of softwoods has a market value from 30 to 60 percent greater than that of the upper common grade. Undoubtedly, for a long time in the future, if not indefinitely, the demand for clear grades of lumber will continue. Whether it will pay to prune will depend upon the differences in price in lumber grades and the cost of pruning, which will vary widely under different conditions.

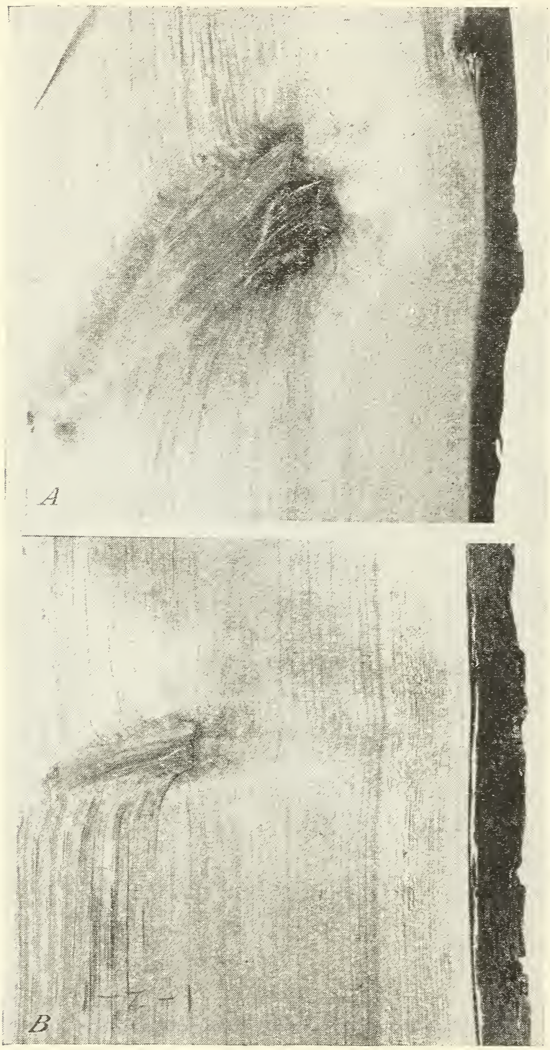


FIGURE 27.—Bad and good pruning practices revealed by overgrown knots: *A*, A jagged and protruding stub required a long time for healing; *B*, branches were removed close to the trunk, leaving smooth, clean surfaces which were more quickly overgrown.

## METHODS OF PRUNING

For low pruning, axes, cutters, and saws are used. Low pruning, where a man can stand on the ground, is not difficult. The chopping off of branches, however, does not always make a good clean cut. For high pruning, pole saws, pole shears, and ladders and hand tools are used, some of which make the work of pruning clumsy and slow. In order to determine whether some more efficient method of high pruning can be developed, the Laboratory (*3*) is exploring the possibilities of power-driven pruning saws (fig. 29). Although the type of pruning saw shown may not be the final answer to economical pruning, it is illustrative of the development work under way. A portable power-driven pruning saw offers possibilities of the more efficient removal of branches in the upper half of a butt log—a gain of considerable importance in stands under intensive management.

## SUMMARY

In plantations of northern white and red pines, dead branches were found to persist for so long a time that little or no clear lumber could be expected in rotations of less than 80 years. Loblolly, shortleaf, slash, and longleaf pines were found to clear their branches more readily, especially in stands containing broadleaved species, where the formation of clear wood begins in from 20 to 25 years. Of the six species studied, complete natural pruning was slowest in northern

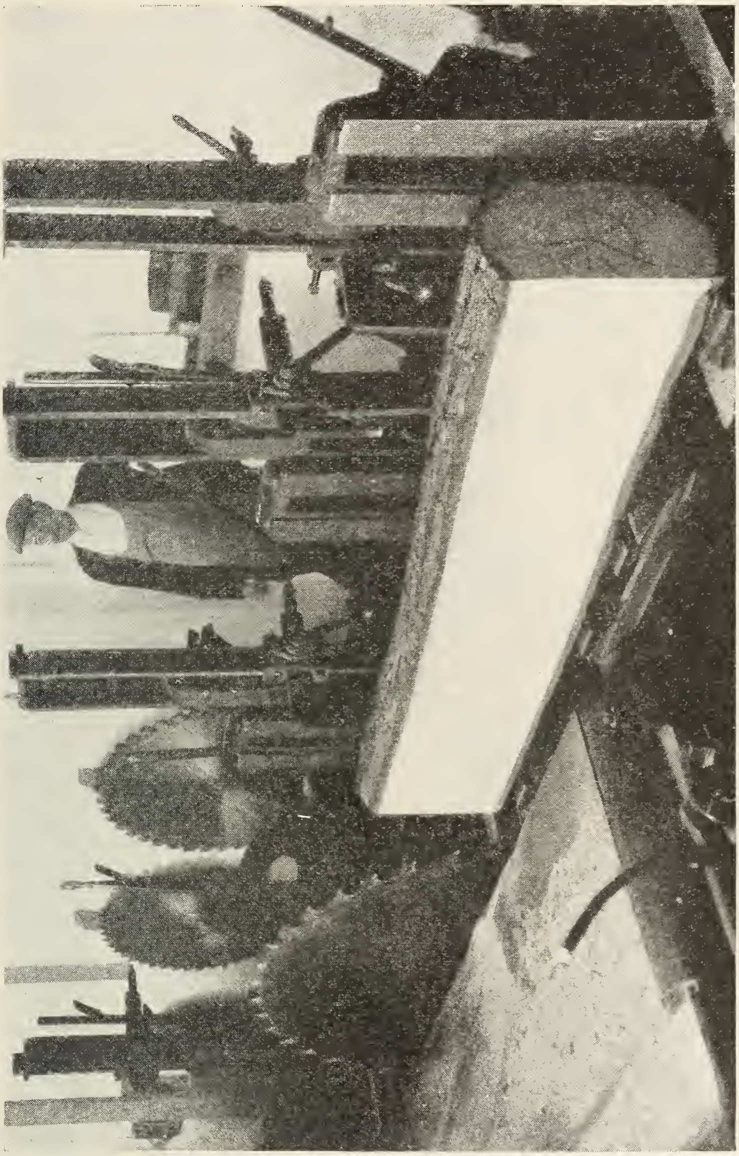


FIGURE 28.—Wide clear lumber was obtained from this red pine pruned 40 years ago.

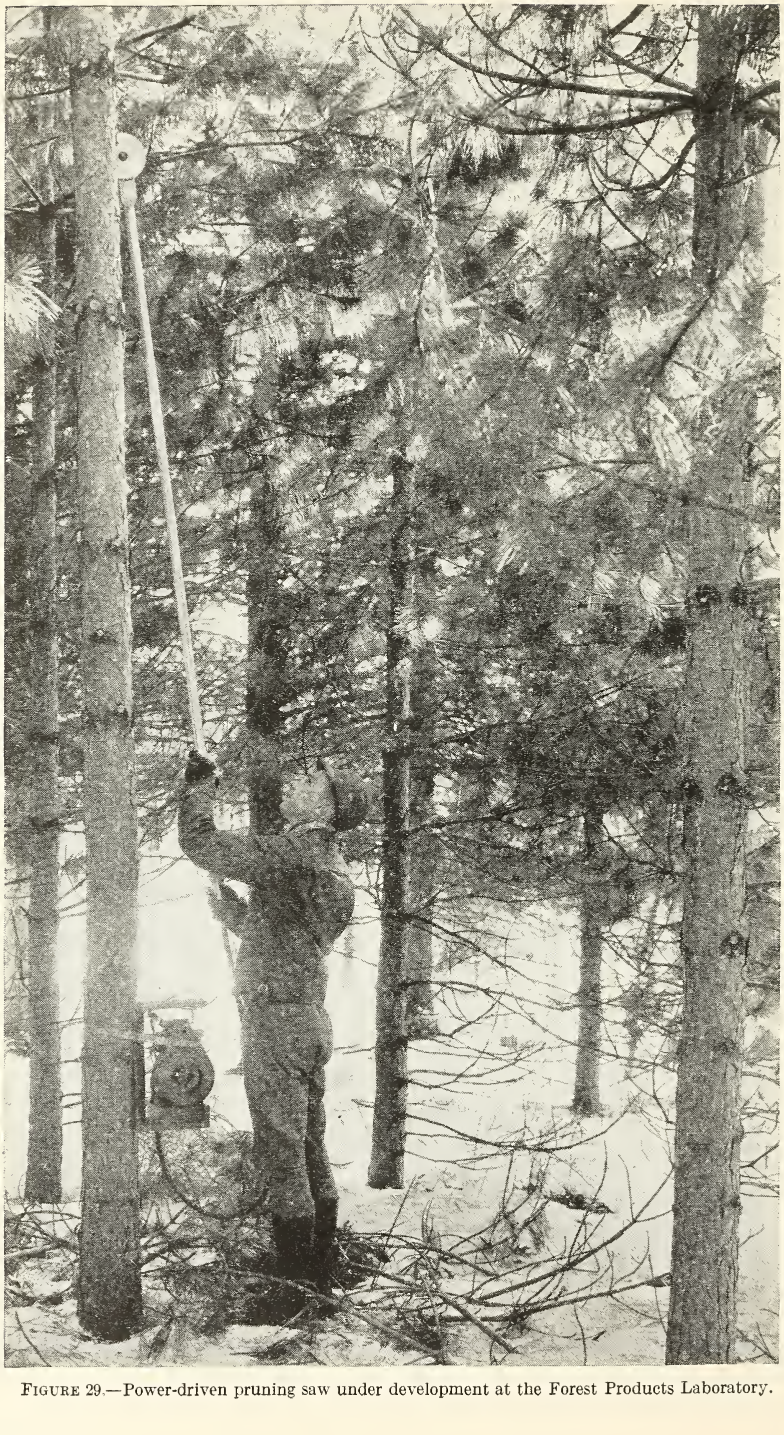


FIGURE 29.—Power-driven pruning saw under development at the Forest Products Laboratory.

white pine. Close spacing in pure northern white pine plantations neither restricted the number of knots formed nor measurably accelerated the time required for complete natural pruning.

Northern white and red pines, which form only one branch node each year, contained more knots in the lower 20-foot length than did loblolly, slash, or longleaf but fewer than shortleaf pine. Of the trees studied, longleaf had knots of the greatest average diameter and shortleaf the least; knots of the largest diameter grew in slash and red pines. No definite relationship was found between the diameter of a branch and the length of time that it persisted after it was dead, in fact smaller branches often persisted longer than did the larger branches of the same species.

The pruning of young trees in sparsely and unevenly stocked stands will greatly improve the resulting lumber grades. In northern white and red pines, even in fully stocked stands, artificial pruning is essential for the production of any of the best grades of lumber in a reasonable time. In pruned trees the branch wounds in northern white grew over in 3 to 5 years; in red in 5 to 7 years. Northern white pine trees pruned 40 years before felling when the stem was only 3 inches in diameter showed 90 percent of the lumber from the pruned section to be entirely clear of knots.

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